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POLARIZED TARGETS AT NAL

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Closely following the arrival of high-energy cross-section information will come the demand for polarization data, especially in elastic processes. Many theoretical models predict "no spin dependence" at very high energy, although there is not total agreement as to what "no spin dependence" means experimentally. Reggeology, in particular, makes definite statements about polarizations as one approaches the "asymptotic region", namely that they should gradually approach zero.

The present experimental data on pp and $\pi^{\pm}p$ elastic scattering show the polarizations to be decreasing with increasing energy, but very slowly. Moreover, the πp polarizations show strong angular dependence even up to 12 GeV/c. The polarization in $\pi^{-}p$ charge exchange, which is expected to vanish at lower than asymptotic energies, is still $\sim$ 20% at 10 GeV/c. (Experiments with beams of other particles are still few in number, and the situation is not yet very clear.) All this indicates that, at the very least, the asymptotic region has not been reached; the measurements will have to be extended to much higher energies. Even if Regge theory should eventually be vindicated, or if for some reason all polarizations should vanish at very high energies, there are predictions of non-vanishing parameters which would be important tests. For example, the spin-correlation parameter C_{NN} provides a test of the factorization hypothesis, and there are other tests involving the various triple-scattering parameters of nucleon-nucleon scattering.

Some proton-proton polarization data can be obtained with polarized-proton beams, although the trend of the available evidence indicates that the traditional technique of making such beams, namely scattering from spin zero nuclei, will yield quite small polarizations at 200 GeV. The other traditional method of obtaining polarization data (analysis of the spin of the recoil nucleon) is limited by the momentum dependence of the analyzing power of all known analyzers to momentum transfers between about 0.5 and 1.5 GeV/c; it also reduces the counting rate by a factor 10 to 100,000 due to the need for one extra scattering.

Aside from investigations of spin dependence at high energy, polarization studies may be useful in uncovering low-spin, high-mass excited baryon states which, because of the unitarity limit, would not show up in the cross-section data.

TYPES OF TARGETS

It is, of course, difficult to predict the developments in polarized targets over the next five years, so I will restrict myself to a description of the present status and some personal guesses as to what we can hope for.

Brute-Force Targets

All the useful polarized nucleon targets thus far have been polarized by dynamic techniques--using microwave pumping. The "brute force" technique may some day become useful--at fields $\geq$ 200,000 G and/or temperatures $\leq$ 0.1° K. The "brute-force" technique on solid (molecular) hydrogen will not work in any case, unless we find a way to turn off the ortho-para conversion. So we will have to use it on things like HD and CH_2. For the time being, however, the various dynamic methods seem sufficiently successful or promising, and the experimental difficulties of brute-force targets sufficiently forbidding, to have effectively stopped all work on the latter.

LMN. Single crystals of lanthanum magnesium nitrate ($La_2Mg_3(NO_3)_{12} \cdot 24\,H_2O$) doped with Nd^{142} have until now proven to be the most polarizable (70%) target material. Only one in 15 protons is a free proton, and the rest of the gunk is unpolarized. But for many experiments (elastic scattering and other two-body final states), determination of both scattering and recoil angles has reduced the background from bound nucleons to about 10%. Moreover, a mixture of various powders has been developed which closely resembles LMN in every respect except that it contains no hydrogen, and this can be used to get the shape of the background (vs angle) so that one can do a background subtraction a la CH_2 - C. The polarization deteriorates after exposure to ~ 10^{14} particles/cm^2, but this is not a problem in most experiments.

For good results a magnetic field of about 20,000 G is required uniform to 1 G over the volume of the target; also several watts of 70 GH_z microwave power, resulting in a liquid helium consumption of about one liter per hour -- a non-negligible operating cost at several dollars per liter!

Alcohols and other organic substances. The art of polarizing these is at present a pharmacist's delight, for there are several dozen possible substances, each to be doped with one of several dozen free radicals, in various concentrations, etc., etc., etc. So far, the best reproducible polarizations are about 40%. These substances offer the advantage that the fraction of protons which are free and polarizable is several times that of LMN, making them much more attractive for experiments with many-body final states and few kinematic constraints. This type of target has recently been used for the first time in a scattering experiment, and we can expect it to be used increasingly in the near future. The radiation-damage properties are similar to those of LMN.

CH_2. Polyethylene can also be polarized dynamically, and in some ways this would make a fine target, because one could eliminate background by CH_2-C subtraction and because the hydrogen density is about twice that of liquid hydrogen. But years of trial have produced only marginally useful (~ 10%) polarizations. However, this business is black magic, and there is always the hope that some alchemist will hit on the right trick.

HD. In principle, hydrogen deuteride can be polarized dynamically, and it would offer a very favorable free-proton content, although in some cases the loose binding of the deuteron might make it difficult to identify free-proton events. One could also polarize the deuterons, giving a target of almost free polarized neutrons. So far, useful polarizations have not been obtained in HD.

YES. This happily named crystal, ytterbium ethyl sulfate, is polarized not through rf pumping, but through level crossing in a rotating magnetic field. This has two great advantages over pumping: the field need not be very uniform, making possible much larger targets and open magnet configurations with larger solid angles available for detectors, and the helium consumption is down by at least a factor 4. A disadvantage is that the polarization cannot be easily reversed without reversing the magnetic field (this is not true for the pumping methods, where the polarization can be reversed by a small change in pumping frequency), and this may lead to difficulties with systematic errors. This difficulty may be avoided by providing for adiabatic reversal. The best polarizations so far obtained are about 35%. About one in 10 protons is free. No YES target has as yet been used in a scattering experiment, but improvements in the technique are being pushed by Jeffries and his collaborators.

Sneakily-polarized HD. In a scheme recently proposed by Honig, one would brute force polarize HD at fields $\geq$ 100,000 G at temperatures $\leq$ 0.01° K (in the newly developed helium dilution refrigerator), wait for the relaxation mechanism -- a small amount of ortho-H_2 -- to turn off (a matter of months!) and transfer the solid HD to a helium bath at 1° K in a field of several kG, where the relaxation time would be on the order of days. This scheme (if successful) would combine the advantages of several other methods and materials--large free proton content, the possibility of large targets, accessibility for detectors, and the possibility of polarized neutrons. Possible disadvantages are the time-varying polarization (since it is simply allowed to decay) and the difficulty of reversing the polarization. Still, it is an extremely attractive scheme.

Optically-pumped solids. This scheme is in its infancy, but offers the possibility of polarized proton targets at room temperature in low-magnetic fields. It is being investigated by Jeffries and collaborators.

TYPES OF EXPERIMENTS

Elastic scattering of protons, pions, kaons, antiprotons, neutrons, etc. on polarized protons (also 2-body final states like $pp \rightarrow \pi d$). Because of the kinematic constraints available, LMN targets are quite suitable. Contrary to an unfortunately widespread notion, the selection of free proton events does not fail at very high energies: The multiple scattering goes as $1/p$, so that the uncertainty in transverse momentum, $p\theta_{rms}$, is independent of p and only depends on the target dimensions and density. The requirement for good-background rejection is that $p\theta_{rms} << 200$ MeV/c (the Fermi momentum). For a 10-cm long

LMN target, $p\theta_{rms}$ = 15 MeV/c. The density of hydrogen in LMN is 0.06 g/cm^3. Since, to achieve a given accuracy, the necessary counting time varies inversely as the square of the target polarization, LMN should remain a favorite target in spite of its low hydrogen content until a better material is polarized to at least 50%. In some cases (e.g. for very small cross sections) alcohol targets already look competitive.

The range of momentum transfer over which this technique can be used is limited at the low end by the range of the recoil protons, and at the high end by the vanishing cross sections. With a 2-mm diameter target, one should be all right down to p = 150 MeV/c [$t = 0.025\ (GeV/c)^2$]. Using only angular correlation and coplanarity, one can generally do business out to where the cross section is down to ~ 0.2 mb/sterad, but this can be greatly extended by also measuring the momenta. The background rejection factor is roughly $200/\Delta p$, where Δp is the momentum-measurement error, in MeV/c, for each particle measured. Measurements up to $-t \simeq 2\ (GeV/c)^2$ have been carried out.

At sufficiently high energies ($\gtrsim$ 30 GeV/c), one could also study charged hyperon proton elastic scattering with a LMN target. The only requirement is that the hyperon stay in one piece long enough to make possible a good angle determination. The same thing holds true for hyperon production if the hyperon is sufficiently fast.

Resonance production, including production of hyperons, K^{o}'s, and other short-lived "stable" particles. Here, with a more than two-particle final state, one would like as much solid angle as possible. The choice of target material depends on the final state -- for an all charged final state LMN might still be best, whereas in the case of missing neutrals, an alcohol or HD target would do better even at considerably lower polarization. In either case, one would like all the triggering help one could get. A polarized target placed inside a moderate-sized streamer chamber is the ideal system for this type of experiment. Technically, this should not be much more difficult than inserting a hydrogen target, but detailed studies have to be made. Resonance production can also be studied with a missing-mass spectrometer; in this case, the quality factor for a polarized target is the polarization times the fraction of free protons, i.e., one would want an alcohol or HD target.

Muon Proton Interaction

Muon beams are many inches in diameter, so one needs a target of comparable dimensions. To get the recoil protons cleanly out of the target, a target of low density is desirable. There is considerable theoretical interest in scattering polarized muons on polarized protons, so the development of polarized HD targets should be of some interest to NAL.

Spin Rotation and Correlation Experiments

Although most theoretical models predict that polarizations vanish at very high energies, they differ in their predictions for higher-order polarization experiments, involving a scattering on a polarized proton and a spin analysis of one of the outgoing particles. In some cases, the effects are supposed to be quite large. These experiments generally require the target polarization to be in the plane of scattering, and this in turn requires either the use of superconducting magnets or targets that do not need a very uniform magnetic field.

FACILITIES AND SERVICE

If one accepts the idea that there will be a demand for the kinds of data which polarized-target experiments can provide at NAL, there are three ways in which NAL can proceed to make such experiments possible:

1. Rely on user groups who wish to do these experiments to supply their own targets, adapted to their own needs, as is presently done at LRL and BNL. This has the advantage of costing NAL nothing in either money or manpower.

2. Establish a permanent service group at NAL to build and operate polarized targets and to develop new techniques, much like liquid hydrogen target or beam separator groups function at most large labs. This is the situation with respect to the polarized-target facilities at CERN. It has the great advantage that the facilities are equally available to any group, and no one with a good idea for an experiment need be deterred by the

prospect of a four-year development project. It also makes possible the development of new techniques independently of immediate needs, which may in turn suggest new experiments.

3. Rely on user groups to build conventional targets, giving them some initial priority in their use but eventually turning these targets into lab facilities. This is roughly what is done with most new bubble chambers. NAL would establish a small group to operate targets during experiments (this requires one reasonably awake technician per target per shift) and to do development work on new techniques. This combines most of the advantages of (1) and (2), and in addition, provides some flexibility in shifting the workload between universities and NAL, depending on the availability of funds and on the intensity of interest at universities vs NAL.

I am strongly in favor of option (3). Particularly, if the technique of polarizing HD by brute force and then turning off the relaxation mechanism continues to show promise, it will be very important to have facilities for this work at NAL, since the hardware involved (100 kG superconducting magnets, He^3-He^4 dilution refrigerators, cold-storage areas for polarized chunks of solid HD) will be expensive, and the preparation of polarized samples of HD will take many months.

I would also like to emphasize that all the methods for polarizing nucleons involve the same techniques --electron-spin resonance, nuclear-magnetic resonance, cryogenics, etc. -- and that a small, high-quality group could work on any or all of these methods, depending on the physics and on user interest.